The Role of Starburst in the Chemical Evolution of Galaxies

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Abstract. In a diagram of metallicity ($\tilde{z}$) vs. luminosity (M_B), the different types of nearby ($Z < 0.05$) starburst galaxies seem to follow the same linear relationship as the normal spiral and irregular galaxies. However, for comparable luminosities the more massive starburst nucleus galaxies (SBNGs) show a slight metallic defficiency as compared to the giant spiral galaxies. Furthermore, the SBNGs do not seem to follow the same relationship between $\tilde{z}$ and Hubble type (T) than the normal galaxies. The early-type SBNGs are metal poor as compared to normal galaxies. It may suggests that the chemical evolution of a majority of the nearby starbursts galaxies is not completely over and that the present burst represent an important phase of this process.

1. Metallicity–luminosity relation for starbursts

Garnett & Shields (1987) demonstrated that spiral and irregular galaxies display a metallicity ($\tilde{z}$) luminosity (M_B) relationship over a wide range of magnitudes. In a recent paper Zaritsky, Kennicutt and Huchra (1994; hereafter ZKH) have shown that the individual $\tilde{z}$ vs. M_B relationships among spirals and irregulars merge to form a correlation that spans over 10 magnitudes in M_B and over a factor of more than 100 in $\tilde{z}$. They have further argued that this correlation is the same as the one found for the elliptical and dwarf spheroidal galaxies (Brodie & Huchra 1992). Finally, ZHK have shown that there also exists a strong correlation between $\tilde{z}$ and the Hubble type (T). They concluded that the abundance properties of the galaxies are imprimed early in their evolution, and are related to the same initial conditions that determine the Hubble types, the gas fractions and the bulge-to-disk ratios.

Following ZHK, the observed correlations of $\tilde{z}$ with mass and Hubble types suggest that stochastic effects, such as starburst, do not affect the global abundance of most galaxies. Contrary to this point of view, we show in Fig. 1 that the two types of starburst galaxies (the HII galaxies and the starburst nucleus galaxies, SBNGs) seem to follow the same linear relationship between $\tilde{z}$ and M_B as the irregular and normal spiral galaxies (see Coziol 1996b, for a complete discussion).

In Fig. 1, it is suggested that for comparable luminosities the SBNGs are slightly defficient in metals as compared to the giant spiral galaxies. In Fig. 2, the few SBNGs galaxies in our sample with a well defined Hubble type are

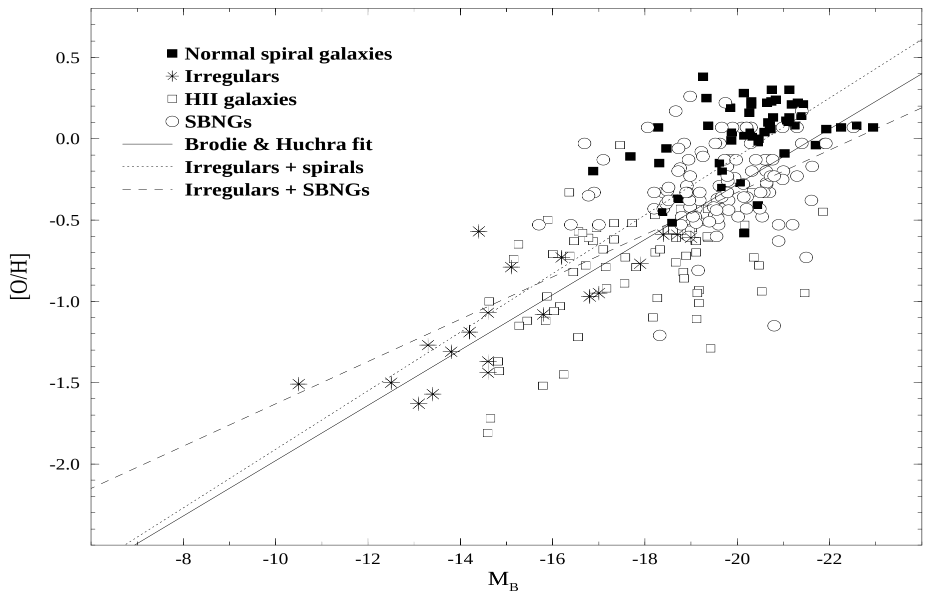

Figure 1. Relationship between z and M_B for the two types of starburst galaxies as compared to the irregular and normal spiral galaxies. The metallicity is given by $[O/H] = \log(O/H)_{gal} - \log(O/H)_\odot$. The giant spirals and irregular galaxies follow a slightly steeper relation than the elliptical and the dSph, while the relationship is flatter for the starburst galaxies.

plotted in a $\tilde{z}$ vs. T diagram. Although the number of galaxies is small, it suggests that it is mostly the early-type SBNGs that are defficient in metals.

The lower metallicity of the SBNGs is incompatible with the usual interpretation of these objects as a brief increase of star formation in a well evolved galaxy (Huchra 1977). On the contrary, the above result suggests that the SBNGs are less chemically evolved than normal galaxies. Consequently, the present burst of star formation could have a significant impact on the chemical evolution of these galaxies. The fact that the starbursts follow a metallicity–luminosity relation suggests also some underlying regulating mechanism. Starburst event is not such a chaotic phenomenon after all.

2. Discussion

What is the cause of the metallicity–luminosity relation for the starbursts, and why are the massive early-type SBNGs less metal rich than normal galaxies? Four different hypotheses are considered. All suppose a metallicity–mass relationship.

Outflows from SNe winds could produce a metallicity–mass relationship. However, such mechanism should be less efficient in massive galaxies, unless we consider superwinds (Heckman, Armus & Miley 1987). Following this model, a SNe rate of 3–30 yr^{-1} could produce outflows of 10–100 $M_\odot\ \mathrm{yr}^{-1}$. If a typical starburst duration is 10^8 yr, a massive galaxy could lose up to 10^9–10^{10} $M_\odot$ of

enriched matter. But, such a violent event seems to fit only one type of starbursts i.e. the ultra-luminous infrared galaxies. It is also difficult to understand how such a catastrophic phenomenon could produce a thight metallicity–mass relation without destroying the host galaxy.

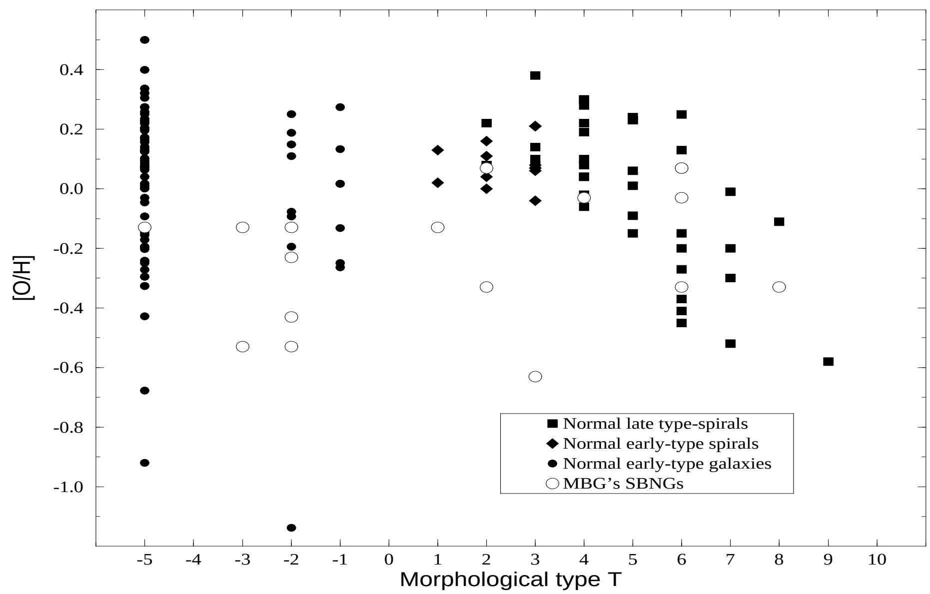

Figure 2. Relationship between $\tilde{z}$ and Hubble type (T) for the normal spiral galaxies and the SBNGs. For the normal early-type galaxies the metallicity really corresponds to the metallicity of the stars, which is given by [Fe/H] (see ZHK for a description of how the metallicities were evaluated).

In principle, massive gas accretion of unprocessed material could diminished the mean metallicity of normal evolved galaxies. Recent accretion is obvious in the SBNGs which posssess unusually high gas fraction for their morphological type (Coziol *et al.* 1995). The presence of some heavy elements also implies star formation, which is expected as new accretion of gas will probably be followed by a new phase of star formation. However, the bursts of star formation have also to last a sufficiently long time in order to modify significantly the chemical composition of the gas. We should imagine also an effective mechanism to bring all this gas in the nucleus. It seems likely that we need a very fine tuning between the different parameters of this model to produce a tight metallicity–mass relation. Finally, it is difficult to imagine how huge reservoirs of gas could still exist in the neighbourhood of massive galaxies.

Tinsley & Larson (1979) have shown that if elliptical galaxies and the bulges of spirals are formed by a gradual merging of small mass elements, a metallicity–mass relationship is produced assuming that the efficiency of the star formation increases with the mass of the merged systems. Following this scenario, a galaxy will also acquire a disk if after the violent merger phase there are still residual outlying gas or gas–rich small subsystems that continue to be accreted. Following Struck–Marcell (1981), this phenomenon produce a higher yield, and

therefore could explain the steeper linear relation observed for the giant spirals. Following this hypothesis, one would have to admit that most of the nearby starbursts are still in the process of forming their bulges. Furthermore, if the SBNGs are results of mergers, we should observe the parent population of these merging galaxies sometime in the recent past.

Following the Stochastic Self–Propagating Star Formation (SSPSF) theory (Gerola, Seiden & Schulman 1980) the average rate of star formation increases with the size of the galaxy and that produces am etallicity–mass relationship. This is because in a large system, the probability that the star formation will percolate into areas which are fertiles increases with the size of the galaxy. Massive galaxies will therefore experienced more bursts of star formation and consequently looks more evolved than small mass galaxies. Following this theory, the starburst are regulated by one internal mechanism with a time duration longer than the usual dynamical time scale of interacting galaxies. Furthermore, all the starbursts are explained by the same mechanism.

3. Conclusion

Of the four scenarios considered above, only superwinds and massive accretion could save the "old " or evolved nature of the host galaxies of the SBNGs. The chaotic nature of the first and the fine tuning of the other seem difficult to reconciliate with a tight metallicity–mass relation. It remains either the multiple mergers scenario or the SSPSF model. These two models suggest that the chemical evolution of galaxies proceeds through a sequence of bursts of star formation. Traces of such sequences may still be detectable in the nearby SBNGs (Coziol 1996a). Both models also suggests that the starburst phenomenon is really a fundamental process of the chemical evolution of galaxies.

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